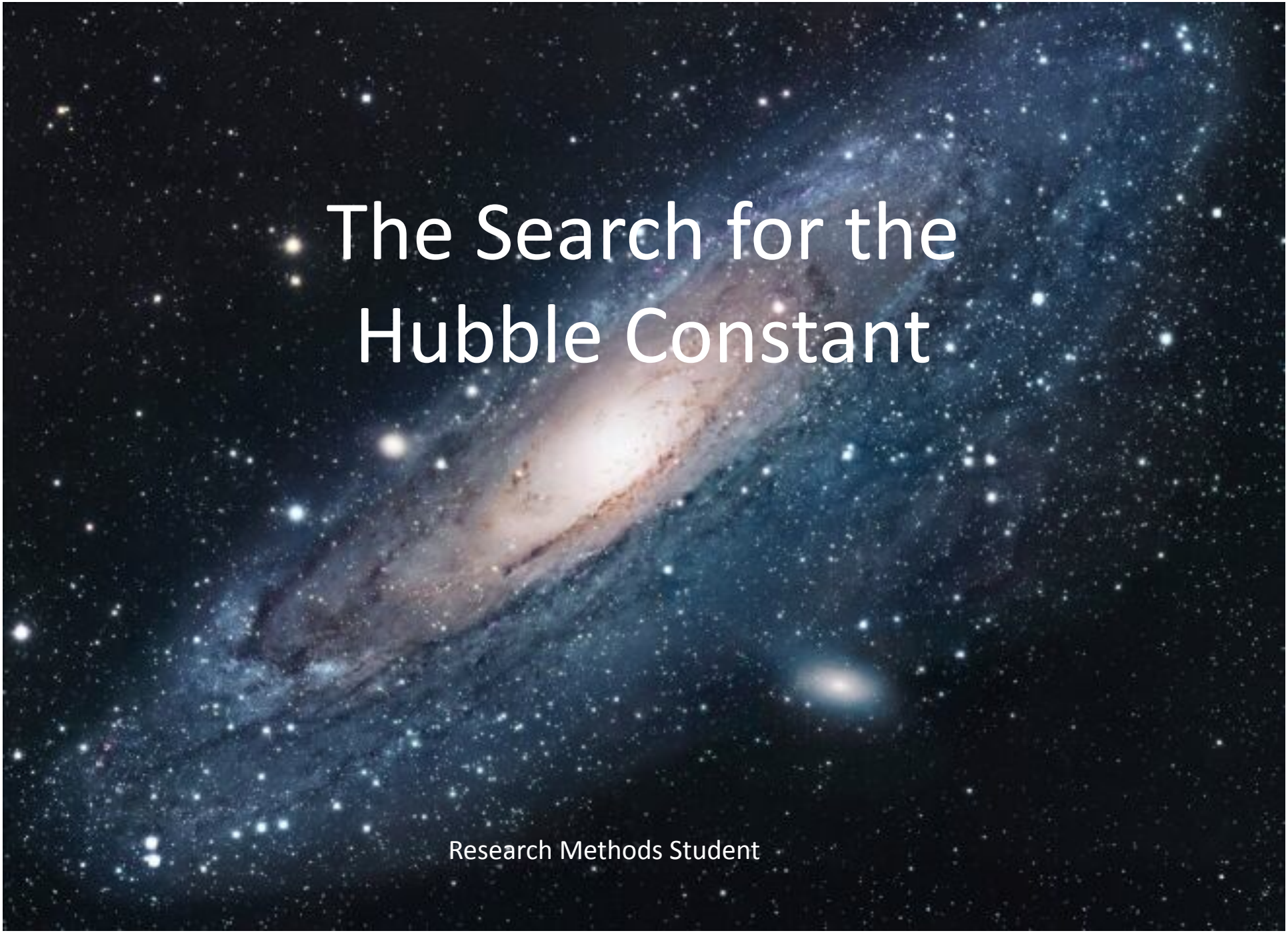


The Huntington Library, San Marino, California

Edwin Hubble

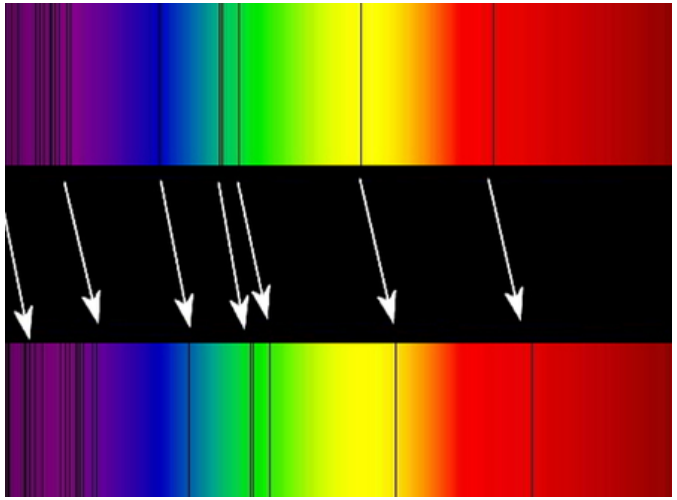
- Father of Observational Cosmology
- Found galaxies outside the Milky Way (1923)
- First to show that the universe is expanding (1929)

The Hubble Constant

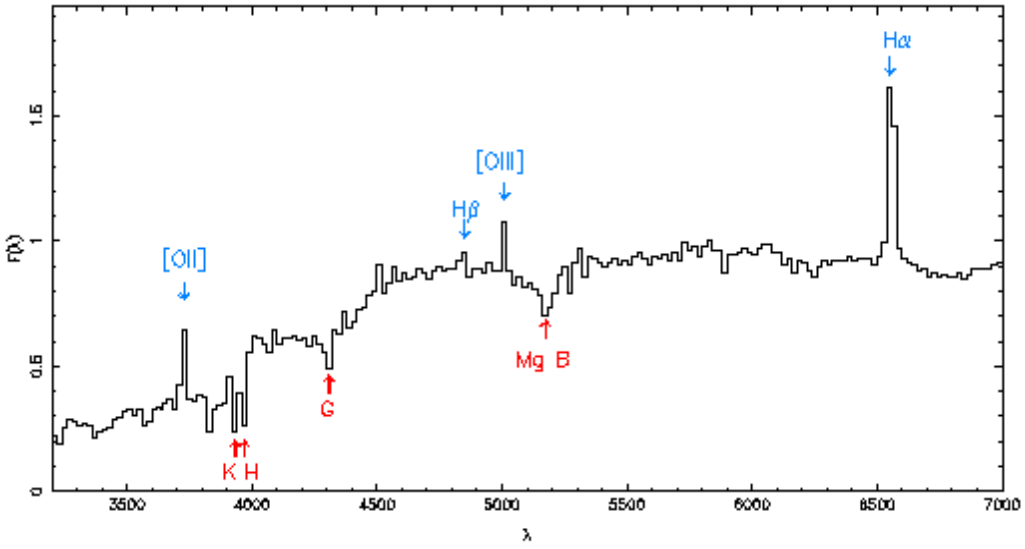
- H_0 is the current rate of expansion of the universe. (the rate of proportion of how fast galaxies and other celestial bodies are receding from us).

Wollack, *Universe 101, NASA* (2010)

Redshift z and Spectra



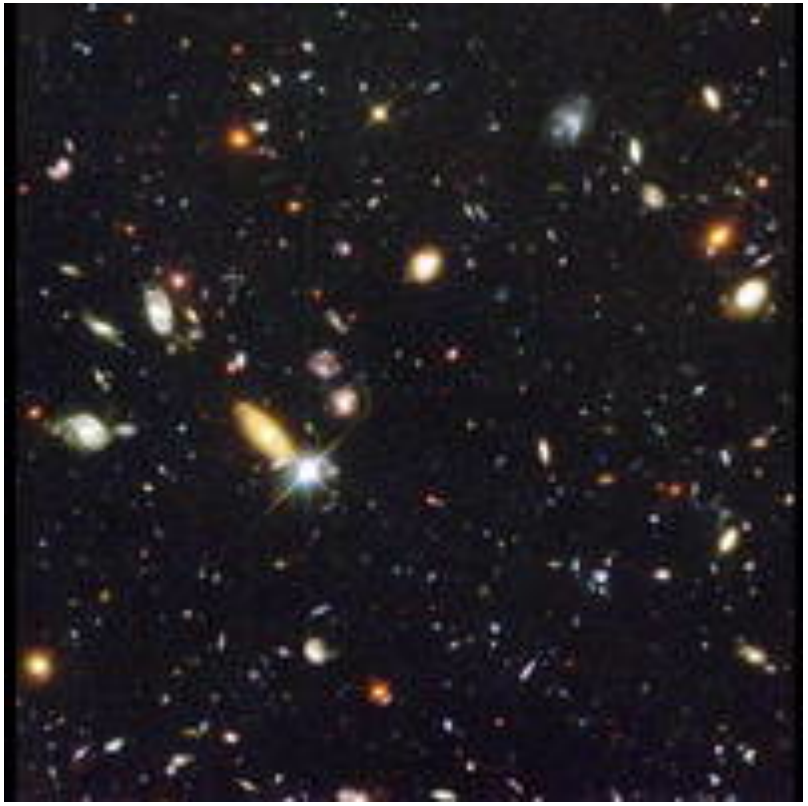
Redshift caused by the wavelength expanding as galaxies move away - wavelengths of light are stretched by the expansion of space.



Spectra show emission lines that can be tracked and measured to find redshift.

Smail, *Measuring the Hubble Constant,* Calculation and Discussion of Results

Angular Diameter d



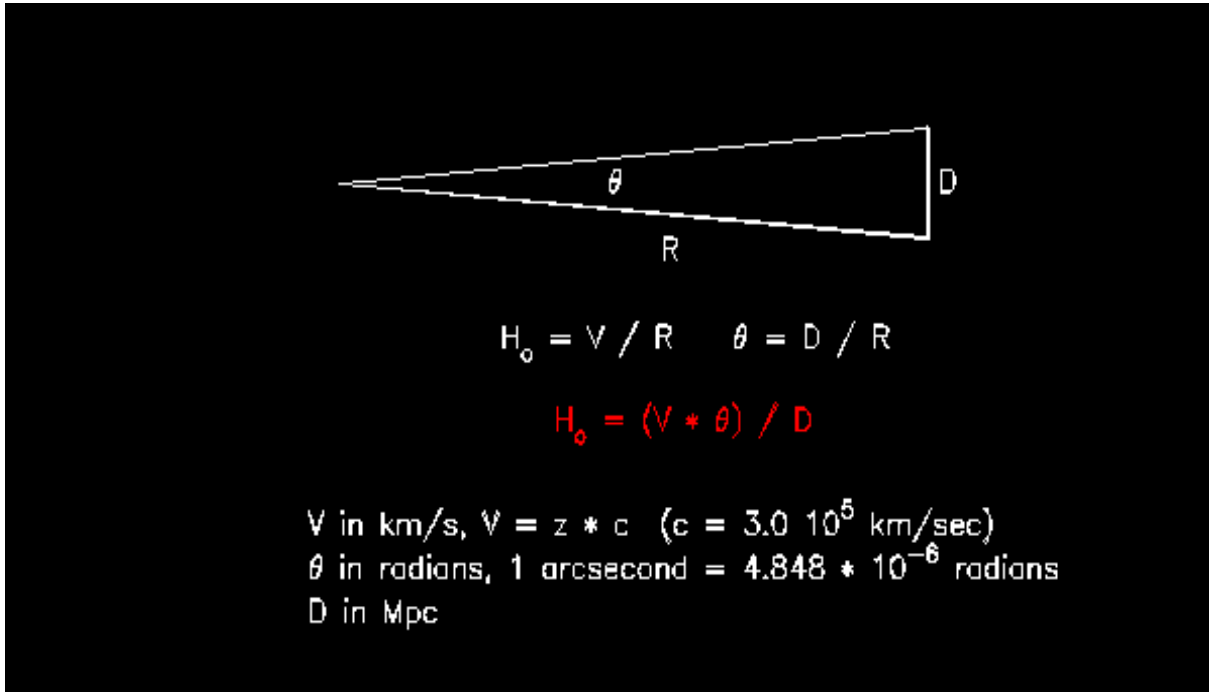
HubbleSite News Center, Hubble Deep Field, Jan. 1996: STScI-1996-01

- Picture of Hubble Deep Field (1500 galaxies shown).
- Measure along major axis – given in arcseconds.

- D = mean diameter of a galaxy = 20 kpc.

(from distance measurements of nearby spiral galaxies)

Formula for Hubble Constant



Smail, *Measuring the Hubble Constant,* Calculation and Discussion of Results

$$H_0 = (V * \theta) / D$$

(units in km/sec/Mpc)

- $V = z * c$

(c = speed of light, units in km/sec)

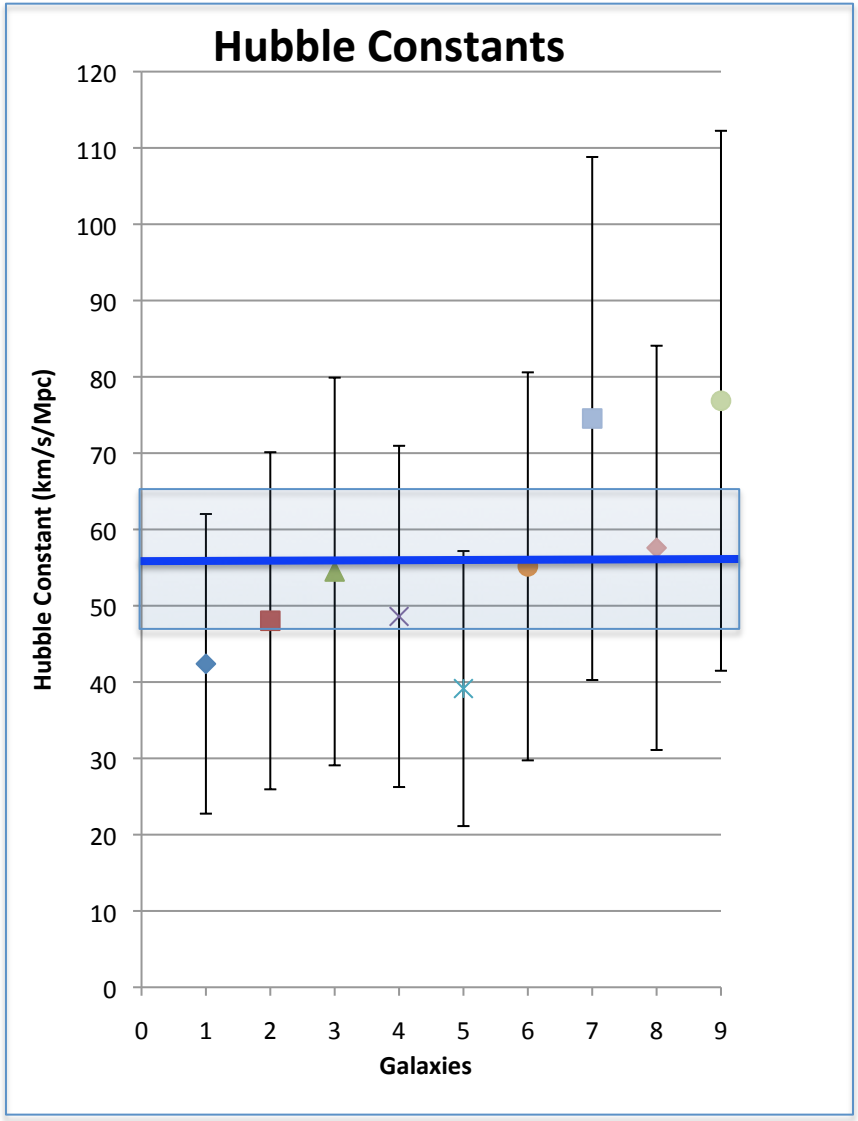
- $D = 0.02$

(divide by 100 for Megaparsecs)

- θ = angular diameter d

(units in radians)

The Hubble Constant



Mean = **55.201 ± 8.691** km/sec/Mpc

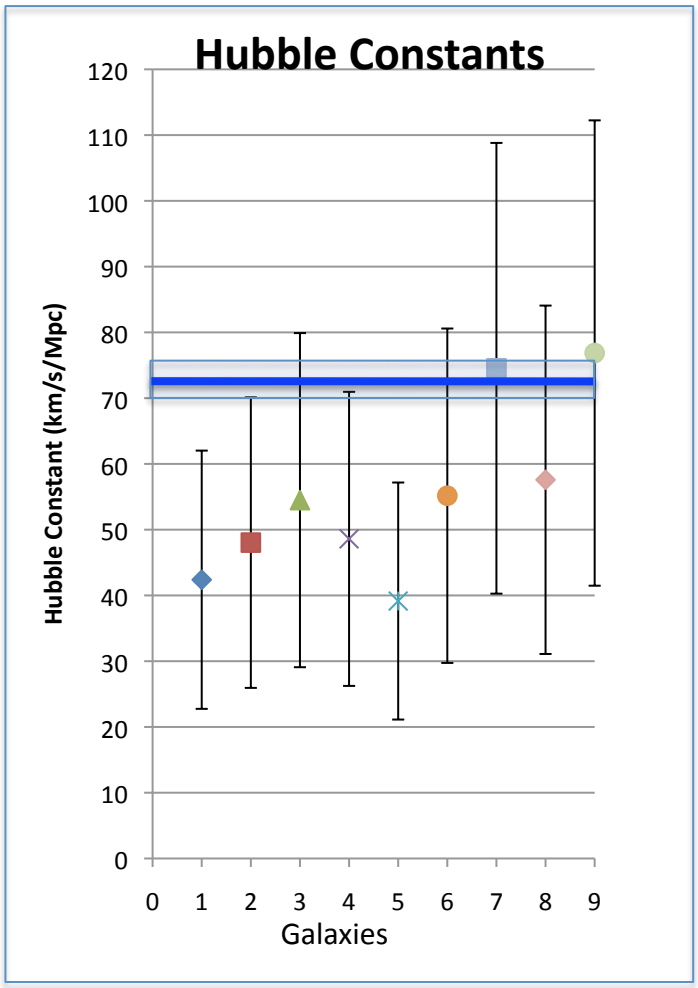
- All the error bars overlap each other.

- Mean goes through every interval for each individual Hubble Constant.

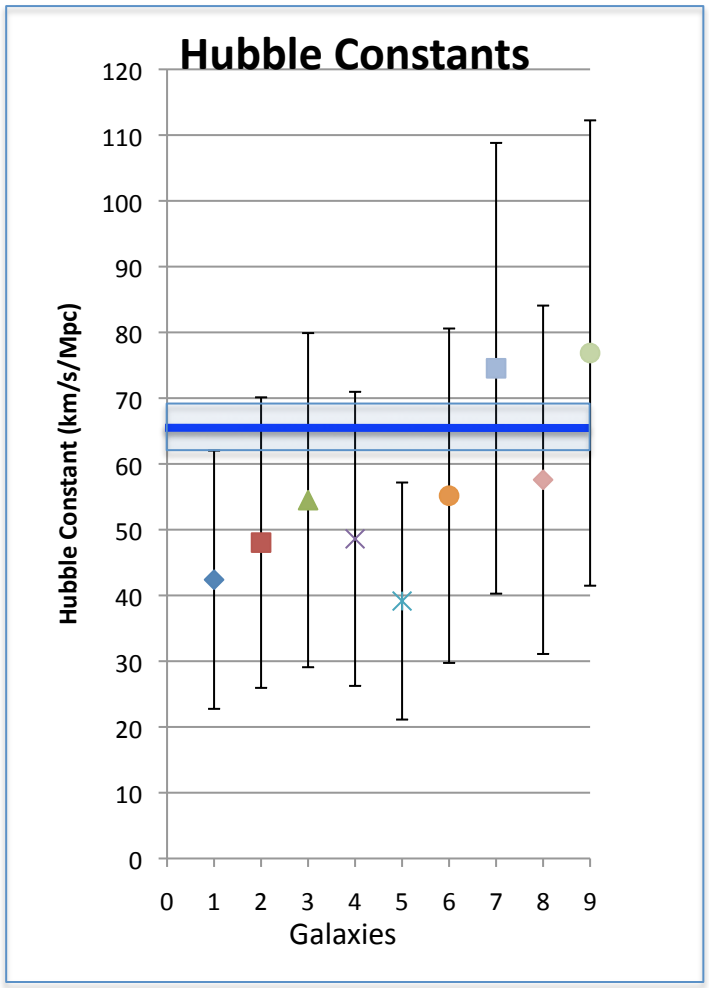
- X^2 Test shows that no statistically significant difference between mean and individual Hubble Constants ($p > 0.25$).

“New” Hubble Constants

- $H_0 = 73.8 \pm 2.4$ km/s/ Mpc
  Riess et al., ApJ, 730.2, (2011)



- $H_0 = 67.0 \pm 3.2$ km/s/Mpc
  Beutler et al., MNRAS 416,(2011)



Hubble's Law

Connection between Velocity and Distance

- Higher redshift -> greater recessional velocity (how fast galaxy is moving away from us)
- As velocity increases, distance from our galaxy increases
- Universe expands so galaxies have someplace to go

The Hubble Diagram

Linear Relationship
between Velocity and Distance: $V = H_0 * D$

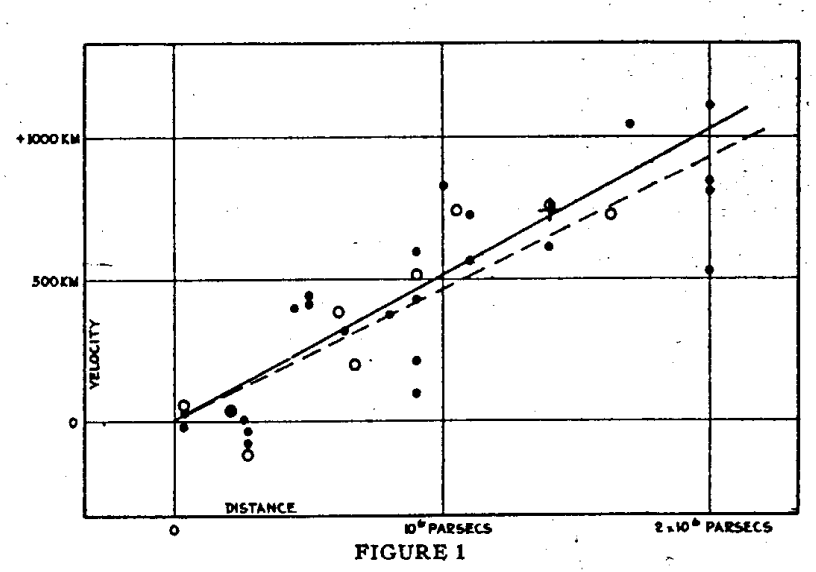
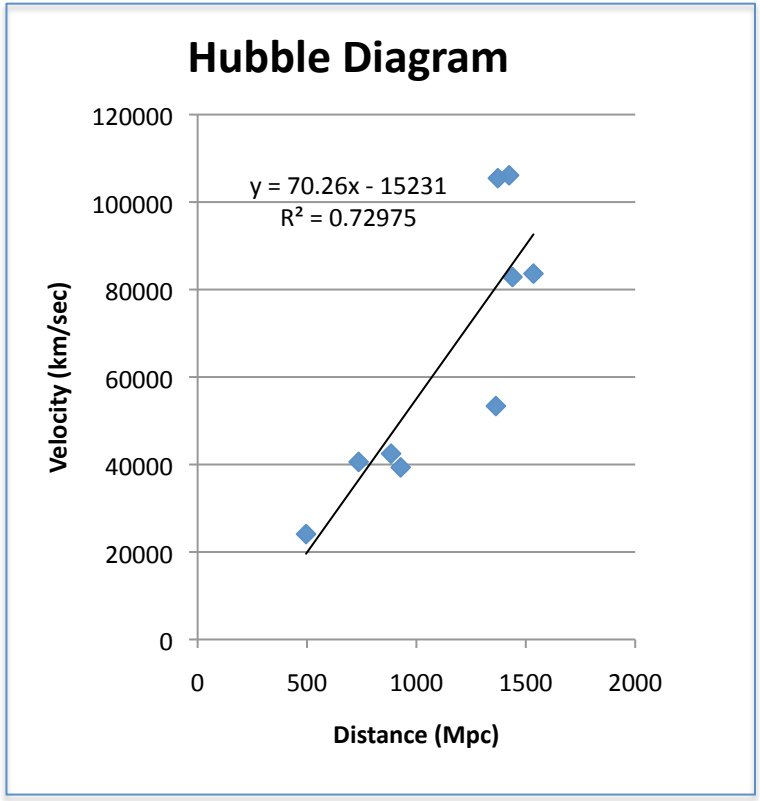


FIGURE 1

Hubble's Diagram: Published in 1929

$H_0 \approx 464$ km/sec/Mpc (slope)



$H_0 \approx 70.26$ km/sec/Mpc
(slope)

Other Findings/Uses with Hubble Constant

- Finds the Age of the Universe (H_0 tells how long the universe has been expanding)

  Current approximation: **14.2 ± 1. 7 Gyr.**

  Reiss, *The Astronomical Journal*,(1998) 116.

- Turns recession velocities into true Distances

  Horack, NASA Science, 2011

- Used to test, predict and constrain properties of Dark Energy and the curvature of space (Ichikawa and Takahashi, 2008)

http://www.fpsoftlab.com/images/screenshots/galaxy-640x480-1.jpg?

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8. Wollack, Edward J. "How Old is the Universe." *Universe 101*. NASA, 19 July 2010. <http://map.gsfc.nasa.gov/universe/uni_age.html>.